SMALL-SCALE BIOGAS PRODUCTION IN THE NEW HOUSING AREA IN MARSABIT

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ABSTRACT

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ABSTRACT

This work explores the possibility of producing biogas in the new housing area in Marsabit, located in north of Kenya, with a dry and arid climate. The relevant conditions for biogas production in Marsabit are described. Biogas is introduced and suitable biogas digesters are discussed, as means to efficiently produce biogas. While challenges are recognized, suggestions to minimize them are offered and immediate benefits of using biogas are shown as well as wider benefits such as impact on deforestation, health, level of education and freeing up time from collecting firewood. Three digestor types were introduced and their suitability for use in Marsabit was considered.

Keywords Biogas, Digestors, Effluent, Marsabit, Renewable

Pages 25 pages

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1 INTRODUCTION

An on-going project in Marsabit, Kenya, aims to build 100 climate smart, affordable and sustainable houses. Marsabit is located in the north of Kenya with a dry and arid climate and it is one of the most underdeveloped regions in the country, where water and energy resources are very limited and the area has been badly affected by the climate change. To combat this, it is planned that the houses use sustainable building technologies, local building materials, natural lighting and ventilation, passive cooling, energy efficient appliances, efficient cooking stoves and renewable energies such as solar, wind and biogas. This document focuses on the aspects of producing biogas as means to secure sustainable cooking while significantly reducing the need for firewood, which would normally be used. Deforestation has been a major problem in Marsabit due to the main cooking fuel at the moment being firewood. Drinking water in Marsabit usually requires some sort of treatment, e.g. boiling, which further increases the consumption of firewood. Moreover, collecting firewood alongside with collecting water is a difficult task which usually falls on the shoulders of women and young girls (Barasa, 2016, p. 48). As a result, a large portion of the day is taken by these chores which minimises or removes completely the possibility for visiting schools and attaining education.

Efficient production of biogas would create a renewable source of fuel for cooking. This would directly impact the region as deforestation would be stopped, cooking and treating water would become easier, agriculture would benefit from an increase in good quality fertilizer and people previously busy with collecting firewood for a good part of the day would have more time to attend possible studies or other important matters.

Biogas technology is not new in Kenya and there are several locations which have implemented it successfully. In Marsabit conditions however, there are still challenges such as lack of kitchen waste and animal manure. In addition to these two, this work also considers using human waste to produce biogas. Conditions and necessary precautions are discussed, to achieve a sustainable biogas production.

The relevant data for the Marsabit area was taken from The Environmental and Social Impact Assessment done for the upcoming project of building the new housing area, the waste survey conducted with 89 households and other reliable sources found in the internet. Literature review was done to find the most suitable biogas production methods for Marsabit conditions. Videos with practical examples of use of biogas were revised and relevant information from them was taken.

2 BIOGAS

Biogas is produced from organic matter through an anaerobic process. In this process, a variety of bacteria converts the biomass fed into the digestor into biogas and liquid effluent. It is crucial, that the process is sealed so that no oxygen enters the system, because the anaerobic bacteria would die. The aerobic composting is totally different process with different bacteria and organisms and should not be mixed with anaerobic degradation and biogas production. The aerobic process works in higher temperatures and converts some of the potential energy into the heat. The anaerobic bacteria can be found for example from cow's stomach or mud in the lakes. The start of the process can be accelerated by using the cow manure or mud from the lake, since they have the bacteria ready. Biogas consists of methane (CH_4), carbon dioxide (CO_2) and possibly some other undesired gases, such as hydrogen sulphide. The higher the methane content, the better the energy value of the gas. (Vögeli, Lohri, Gallardo, Diener, & Zurbrügg, 2014, pp. 11, 24)

When organic waste is handled in the digester, it reduces the number of flies and mosquitoes, since they will not have as many places to reproduce. Therefore, it also helps to prevent the diseases they could potentially spread. (Guyana Energy Agency, p. 2)

2.1 Process of biogas production

The biogas production requires organic matter, which is then transformed through several steps into biogas and nutrient rich digestate. This process is illustrated in Figure 1.

Hydrolysis is the first step of the process. In this step the bacteria disintegrate protein, carbohydrates and lipids into amino acids, sugars and fatty acids. The second step is called acidogenesis, in which the acidogenic bacteria converts the sugars and amino acids into ethanol, acids, acetate, ammonia, hydrogen (H_2) and CO_2. In the third step the acetogenic bacteria brakes long chain fatty acids, volatile fatty acids and alcohols to hydrogen, carbon dioxide and acetic acid. This stage is called acetogenesis. The final stage is called methanogenesis, in which the methanogenic bacteria convert hydrogen and acetic acid to methane and carbon dioxide. (Vögeli, Lohri, Gallardo, Diener, & Zurbrügg, 2014, pp. 24-25)

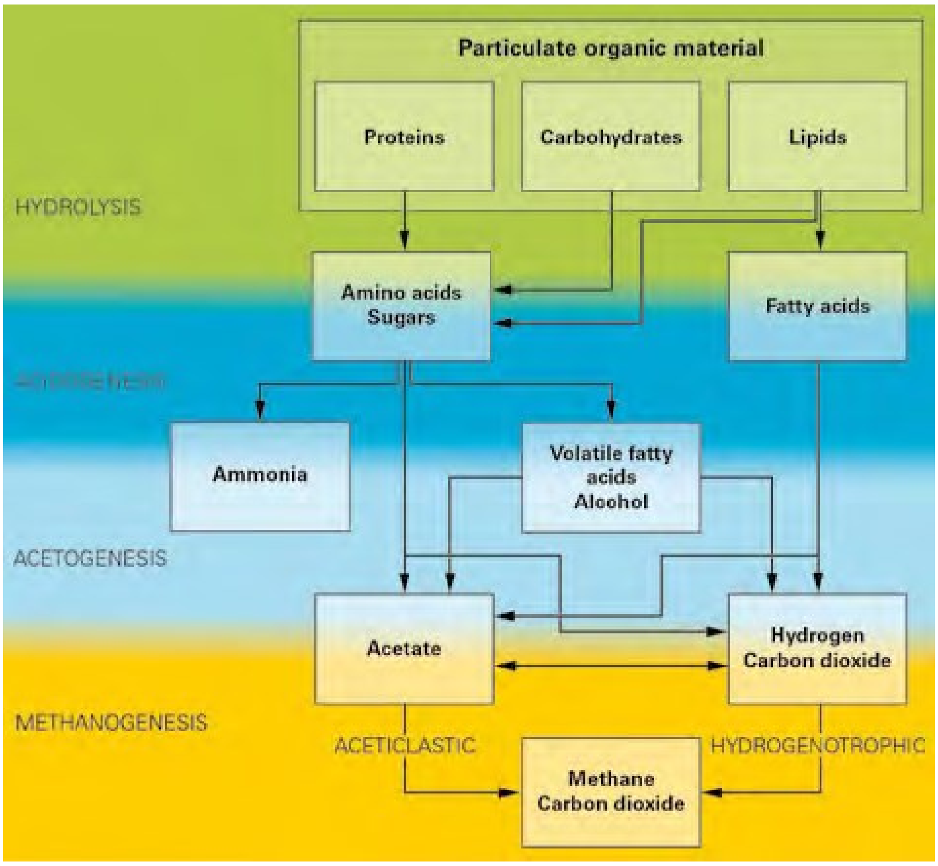

Figure 1. Process chart of biogas production. (Vögeli, Lohri, Gallardo, Diener, & Zurbrügg, 2014, p. 24)

2.2 Conditions for biogas production

For the process to function properly, certain conditions must be met. Different stages of anaerobic digestion require different conditions. However, in small scale digestors, all these steps are happening in the same digestor and therefore the best results may not always be acquired. The process still functions in sufficient enough level and biogas is formed. These requirements are temperature, pH and carbon-nitrogen ratio. The environmental aspects (temperature) and organic material fed to the digester will affect to these conditions.

The process is the most stable when it is operating at mesophilic range (30-40°C, optimum 37°C). The mesophilic bacteria need less energy and are not so sensitive for changes in the conditions. Operating in thermophilic range (45-60°C, optimum 55°C) is faster, but the thermophilic bacteria are more sensitive to the changes in other parameters. (Vögeli, Lohri, Gallardo, Diener, & Zurbrügg, 2014, pp. 26-27, 32) Operating in psychrophilic range (0-15°C) is not very feasible option due to the long retention time (100-300 days, vs. mesophilic 20-40 days). (Shrestha & Shrestha, 2019, p. 20) (Octaform, 2011, p. 5)

The aimed pH is 6.5-7.5. Different stages of the process function best in different ranges. Hydrolysis and acidogenesis need more acidic environment (pH 5.5 - 6.5), whereas the methanogenesis occurs in higher pH level (pH 6.5 - 8.2). In case the pH gets too acidic, for instance lime, sodium bicarbonate or sodium hydroxide can be used for increasing the pH. (Vögeli, Lohri, Gallardo, Diener, & Zurbrügg, 2014, p. 27)

Different organic waste fed for the digester have different amount of carbon and nitrogen. If too much nitrogen is fed to the system, the ammonia content gets high and the pH increases due to the ammonia accumulation. On the other hand, too less nitrogen is not good for the process either as it can decrease the gas production. The optimal Carbon – Nitrogen (C:N) ratio varies between 16-25:1. (Vögeli, Lohri, Gallardo, Diener, & Zurbrügg, 2014, pp. 27-28)

The hydraulic retention time (HRT) tells the time the organic waste stays in the reactor. The HRT depends on the conditions and the organic waste fed into the digester. The more optimum conditions, the shorter the retention time. While operating in the mesophilic range, the HRT is 10-40 days. The HRT is calculated by the ratio of active slurry volume and input flow rate of feedstock. (Vögeli, Lohri, Gallardo, Diener, & Zurbrügg, 2014, p. 29)

2.3 **Feeding the biogas digester**

For the digester to work, organic matter needs to be fed into the digestor regularly, preferably every day to ensure constant gas production. The amount of waste depends on the size of the digestor, as well as the waste fed into the system and the operating temperature. Basically, any kind of organic waste can be put to the digestor. However, material high in lignin (e.g. wood) cannot be broken down in anaerobic conditions. Some digesters might be running purely on cow dung or sludge from municipal wastewater treatment centres. In household scale they might be run only on biowaste generated from kitchen and grass clippings etc. Different types of organic waste can also be mixed. It is possible to use manure from the animals, human waste and biowaste mixed all together. Biowaste has higher energy potential than faeces (see Figure 2), since they have been going through the process already once (e.g. in cow's stomach). (Vögeli, Lohri, Gallardo, Diener, & Zurbrügg, 2014, pp. 11-12, 15-17, 21-23, 30, 45)

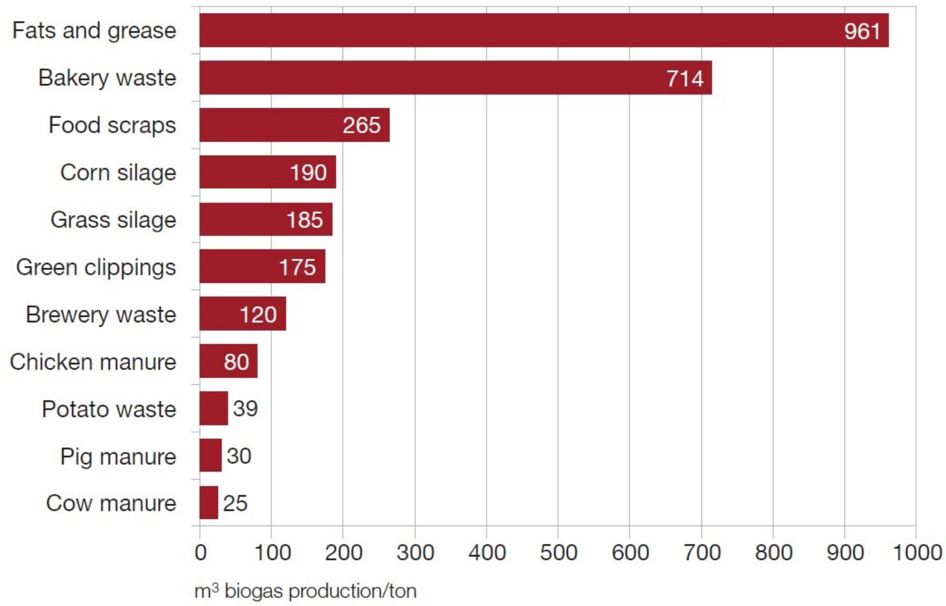

Figure 2. Biogas production potential of different materials. (IFAD, 2012, p. 33)

Research conducted showed that adding plant-based waste increases the gas production significantly. This can be seen in the Table 1 with the daily gas production per person. However, the methane content of the produced gas was lowered due to the carbohydrate content of the kitchen waste. This results in higher carbon dioxide levels in the gas content. (Lohri, et al., 2010, pp. 1, 5)

Table 1. Human waste vs. human waste and kitchen waste. (Lohri, et al., 2010, p. 5)

		Jail 1 10m3	Jail 1 20m3	Jail 2 10m3	Jail 2 35m3	Jail 3 10m3
Expected number of detainees [pers.]	*2007*	*68*	*119*	*115*	*206*	*74*
Observed number of detainees [pers.]	April - June 2009	65	135	115	155	106
Expected kitchen waste feeding [kg/d	*2007*	*4*	*43*	*0*	*73*	*0*
Observed kitchen waste feeding [kg/d]	April - June 2009	3	45	0	3	0
Expected gas production [L/d]	*2007*	*2'000*	*4'000*	*3'000*	*7'000*	*2'000*
Measured gas production [L/d]	**June 2009**	**2'120**	**9'210**	**3'310**	**4'800**	**3'450**
Difference between expected and measured gas production [%]		+6%	+130%	+10%	-31%	+73%
Daily gas production per person [NL/pers./d]	June 2009	29.5	61.9	25.9	27.9	29.2
Gas burning period [h/d]	June 2009	6.5	19.5	9	10.5	9.5

It is beneficial to chop down the waste put in the digester for example by using food processor or blender. In case electrical appliances are out of question, the waste can be left in the sun with water for couple of days for it to get softer and/or smashed by hitting it with a piece of wood, to reduce the size of the waste particles. Besides the organic material, water is also needed. The effluent can also be reused and fed back to the system. This can be used to accelerate the process. The other option is to utilize greywaters in the system if it is not having detergents. Usually the ratio of 1:1 of organic matter and water is recommended, so that the waste fed into the digester forms a sort of a slurry as can be seen in the Figure 3. This digests faster and does not clog the inlet tube as easily as bigger particles would. As a result, also smaller inlet pipes can be used than if bigger particle size would be fed. (Vögeli, Lohri, Gallardo, Diener, & Zurbrügg, 2014, pp. 21-23, 28, 45) (Culhane, Katey, & Pape, 2011, p. 5)

Figure 3. Feeding the digester. (IFAD, 2015, p. 15)

2.4 Effluent/ Digestate

When organic matter is fed to the system, equal amount of effluent comes out from the other end. This can be used as a fertilizer to crops, trees etc. It has been shown that crops fertilized with the effluent grow better. The low-income households can grow at least part of their own food without needing to buy artificial fertilizers, and the effluent based fertilizer thus helps them achieve better nutrition. (Vögeli, Lohri, Gallardo, Diener, & Zurbrügg, 2014, pp. 22, 65, 68) (World Health Organization, 2006, pp. 7, 29) (IFAD, 2015, pp. 2, 6-7, 17)

If human faeces have been put into the digestor, hygieniation is recommended, because of bacteria, viruses, and parasites. However, this is not considered a very big issue, especially, if the faeces were from the same household utilizing the effluent. Temperature and hydraulic retention time affect to the hygienisation level needed. If the digestor is operating in the thermophilic range and the HRT is two weeks, this is enough for killing the pathogens. However, mostly small scale digestors function in mesophilic range and although the amount of pathogens has been reduced significantly during the process, some are still left. The longer the matter stays in the digestor, the less pathogens are left. (Vögeli, Lohri, Gallardo, Diener, & Zurbrügg, 2014, p. 32. 64)

WHO recommends storing faecal sludge 1.5-2 years in 2-20°C and more than 1 year in 20-35°C. This should lower the level of pathogens to level that it is safe to use. Thermophilic digestion in temperature above 50°C for two weeks should destroy the pathogens. The slurry can also be treated by for example pasteurizing, high-alkaline treatment (raising the pH above 9) or extended storage. However, these methods are difficult to put in action in a household scale. (World Health Organization, 2006, pp. 42-44, 63, 68-69, 90-93)

Most of the time, the effluent is utilized straight from the digestor. This, of course, does pose a threat, but there are other measures that can also be done. Anaerobic digestion significantly reduces the amount of pathogens and it is considered already a treatment method itself. To further ensure the safety of the crops, WHO for example recommends minimum one month of waiting time between applying the effluent as a fertilizer and harvesting the crops. The effluent can be used for seeds with the vegetables consumed raw. It is also found, that for example the surface of the crop matters. Vegetables with smooth surface have less pathogens. Washing the crops with clean water gets off most of the pathogens. Cooking the produce will make them safe to consume, as the heat kills the pathogens. For the fruit trees and others where the effluent does not touch to crop, the fertilizer can be utilized at any given time. (World Health Organization, 2006, pp. 42-44, 63, 68-69, 90-93)

2.5 **Gas**

The other main product, besides the effluent, is biogas. Biogas consists mainly on methane (CH_4) and carbon dioxide (CO_2). Small amounts of hydrogen sulphide (H_2S) is normal. If the gas is used for cooking, there is no need to remove the impurities. However, if the gas is used for combustion engines, high methane content is needed (>96%) and therefore H_2S must be removed and the CO_2 content must be lowered. (Vögeli, Lohri, Gallardo, Diener, & Zurbrügg, 2014, pp. 25-26, 55)

When storing the gas, CO_2 occupies place which can be used by CH_4. Methane (CH_4) is the desired gas and therefore minimizing CO_2 will increase the storage space for CH_4. However, the biogas is mainly used as it is forming (continuously, e.g. for daily cooking, water boiling), so storage might not always be necessary. The content of methane in biogas must be over 45% (typically 55-70%), so that the gas is flammable and can be used for cooking purposes. The content of carbon dioxide is typically between 30-40%. Hydrogen sulphide gives the gas the smell of rotten eggs, but in small amounts it is not harmful and gives the benefit of detecting possible gas leakages. However in big contents, H_2S is toxic and it can cause headaches and breathing problems. (Vögeli, Lohri, Gallardo, Diener, & Zurbrügg, 2014, pp. 12, 25-26, 55-57) (Guyana Energy Agency, p. 4). After the biogas has been formed, it can be used directly for cooking using a biogas cooking stove, as seen in Figure 4.

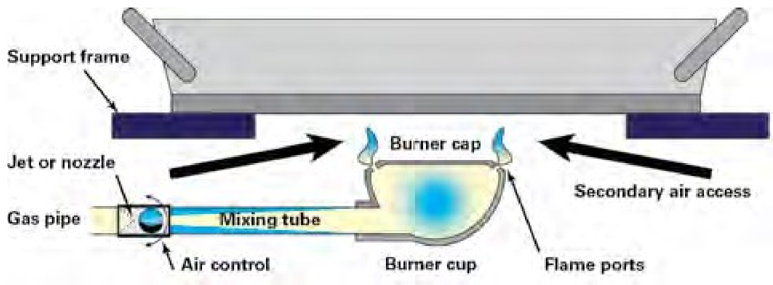

Figure 4. Biogas stove ((Vögeli, Lohri, Gallardo, Diener, & Zurbrügg, 2014, p. 58)

3 BIOGAS DIGESTORS

The biogas digestor size should be chosen based on the amount of waste and the need of gas. If too big digestor is chosen, it will not work efficiently. Bigger digestors also cost more money, so if too much gas is produced and it cannot be sold out, they might not pay themselves off very fast, if not at all.

The simplest digestors can be built to some old containers or barrels (see Figure 5 and 6). There are ready small-scale digestors in the markets for small households or even small farms. These two options are light weight and easy to transport if needed. They can also be set up on rented land. Digestors can also be built from bricks, but they require some skills with the bricklaying. These are fixed to their place, so the land needs to be owned. They are usually longer lasting, but more expensive.

Tree types of digestors where chosen as an option for Marsabit conditions. First is a do-it-yourself digester, IBC-container. Any barrel or container could be used based on, what is available locally. This can be a cheap option but does require some information about biogas digestors. However, they are simple to build and internet is full of instructions. Next option is Flexi biogas, which is produced in Kenya. It is easy to move, if needed and fast to install. It is cheaper than fixed dome digester but the lifespan is shorter. Fixed dome digestors are traditional small-scale biogas digestors. They require time and expertise to build, which means that they are more expensive.

Figure 5. Digestor made out of a barrel. (Culhane, Katey, & Pape, 2011, p. 10)

Figure 6. Horizontal digestor made out of several barrels. (Culhane, Katey, & Pape, 2011, p. 47)

The digestor has an inlet pipe, from where organic material is fed into the digestor. The digestor could also be connected straight to a toilet, so the faeces do not need to be handled separately. As waste goes in, same amount in volume of digestate needs to come off from the other end (the outlet). The effluent can be directed to a bucket and straight to a garden or kept for further treatment. Some digestors also have composting pits (see Figure 7), where the effluent is directed and used only after some time. Often the gas is directed straight from the digester to kitchen for direct use. In some cases, the gas is stored separately, if there is over production. There are separate bags sold for this purpose or another popular storage method is to use inner tyres to store the excess gas.

Figure 7. Composting pits for effluent. (Bhavan, 2013, p. 32)

3.1 **IBC-container**

IBC-containers are popular building material for small scale bio-digesters. They are generally easy to get all around the world and in many cases they are problem waste, which makes them free. Besides the container itself, some pipes, seals and paint are needed. The container should be painted black if kept outside, because the anaerobic bacteria are sensitive to light. In some cases, stones on the bottom of the tank or different kinds of plastic pieces swimming in the tank are used, to increase the surface area for the bacteria, as can be seen in Figure 8 to enhance the biogas production.

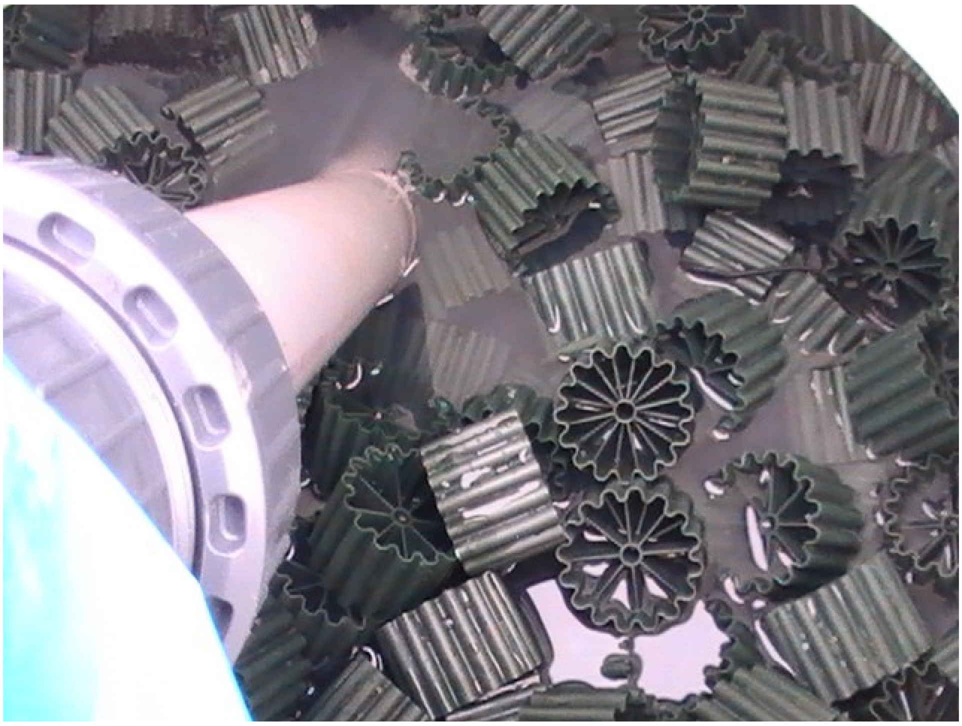

Figure 8. Increasing the surface area with plastic pieces. (Culhane, Katey, & Pape, 2011, p. 26)

Inlet pipe is usually put so that the end is close to the bottom of the digester and it is cut at an angle, so that the material fed comes out easily (see Figure 9). The diameter can vary based on what size tubes are easy to find and also depending on the size of the particles fed into the digester. If the waste fed to the digester is ground up, then a smaller diameter of the tube is sufficient.

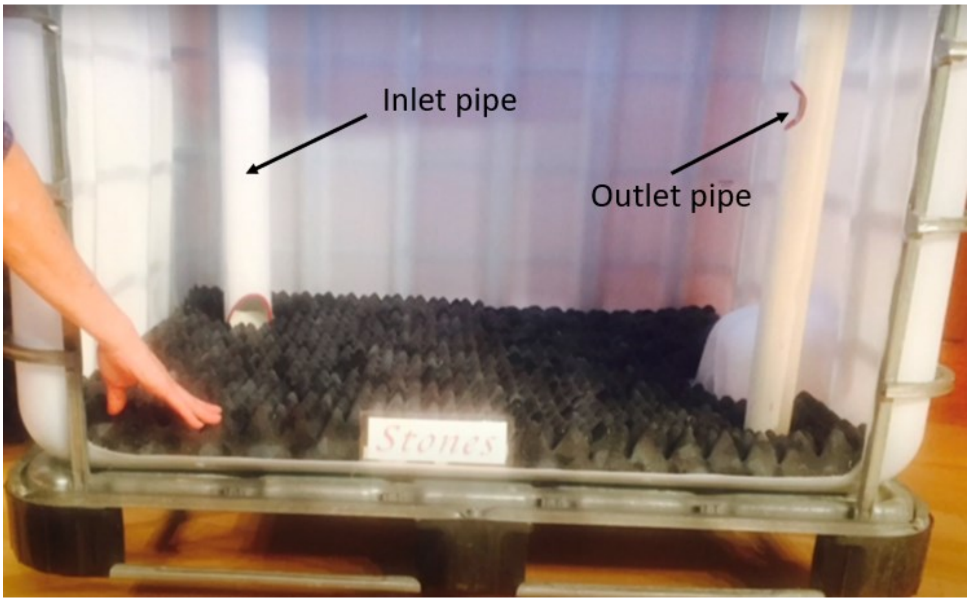

Figure 9. Inlet and outlet pipes. (TEDx talks, 2015)

A hole is drilled in the middle of the outlet pipe (shown in Figure 9). Heavier particles sink to the bottom of the digester and oils and other lighter particles float on top of the surface. This ensures that processed waste exits the digester. This hole in the middle of the outlet pipe should always remain under the level of liquid waste (slurry). If the slurry drops under the hole, then biogas will escape from the outlet pipe. Inlet and outlet pipes are located to opposite side of the containers as can be seen in Figure 10.

Figure 10. Inlet, outlet and gas tubes in IBC-container. (TEDx talks, 2015)

The gas bubbles form in the slurry and gas floats up above the slurry level (top area of the container). From here it can be directed straight to use or to storage. At the lowest point of the gas outlet tube (transparent pipe shown in Figure 10), a valve should be added to remove water vapour formation which can block the tube and the gas will not reach the cooking stove or storage tanks. Water forming in the gas pipe is a common issue if the gas is not coming out.

3.2 **Flexi Biogas**

An example of ready plant for small scale use is the Flexi Biogas, manufactured in Kenya and it is a tubular digestor. It is easily set up (takes less than a day) and it can easily be moved (weights about 50 kg). It comes with a greenhouse tunnel, in which the digester bag made of plastic is placed. The plastic bag is inflating due to the gas formation. The greenhouse helps to heat and trap the heat, which makes the system operating temperature higher (36°C) and lowers the retention time (15 days). The greenhouse protects the actual digestor but needs to be replaced approximately every five years. Digestor itself is said to last up to 10 years. An example of the Flexi Biogas plant can be seen in Figure 11. (IFAD - International Fund for Agricultural Development, 2012, pp. 1-4) (IFAD, 2015, pp. 1-5, 7, 19)

Figure 11. Flexi Biogas digestor. (IFAD - International Fund for Agricultural Development, 2012, p. 1)

The system and its installation (shown in Figure 12) costs about US$410-600 (US$600 version includes the stove, prices estimated on 2015). This is planned for 20kg of cow dung/ day (equals to 1-2 cows) and provides 1000 l gas per day (equals to 120 minutes of cooking). In case cows or other farm animals are not available (or their faeces), the system can also be run with kitchen and garden waste. The need of plant-based waste is less, only 5-10 kg/ day. The organic wastes can be mixed as well. Organic waste should be fed to system mixed with water, in a ratio 1:1. (IFAD - International Fund for Agricultural Development, 2012, pp. 2-4) (IFAD, 2015, pp. 1-5)

Figure 12. Installation of Flexi Biogas. (IFAD, 2015, p. 13)

Tubular digestors can also be self-made if all parts can be found. This may be a cheaper option than buying a ready one, however, it requires some knowledge. In Figure 13 the structure of a tubular digestor is shown. The inlet and outlet pipes should be below the slurry level or the gas will escape. On top there is the pipe for the gas outlet. In case the pressure in the gas line needs to be increased some weights can be put on top of the digestor (e.g. bags of sand).

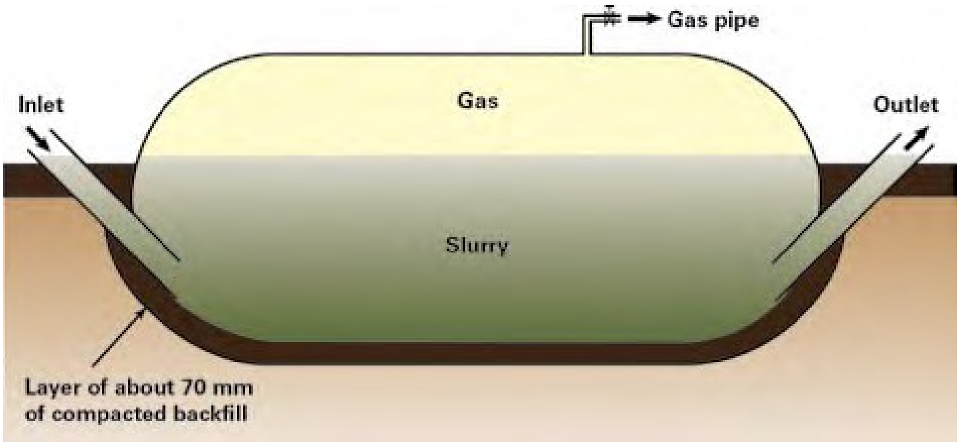

Figure 13. Tubular digestor. (Vögeli, Lohri, Gallardo, Diener, & Zurbrügg, 2014, p. 38)

3.3 **Fixed Dome**

Building the fixed dome biogas digester requires professionals and takes an estimated 21 days to set up. It is built underground, which keeps the temperature more stable, but on the other hand keeps it also colder (operating temperature 19°C) and therefore the retention time is longer than in Flexi Biogas (retention time of 45 days). Fixed domes are said to last up to 20 years. The systems cannot be moved, so they cannot be taken elsewhere in case of moving. The cost of building is estimated to be around US$1200 for 6 m^3 digester and US$750 for 4 m^3 digester (cost estimated in 2015). The smaller version requires 30 kg of dung per day (equals to 3 cows), giving 500-600 l of gas per day (60 minutes cooking time). The bigger version requires 40 kg of dung per day (equals to 3-4 cows) providing 1000 l of gas per day, which means 120 minutes of cooking time per day. (IFAD - International Fund for Agricultural Development, 2012, pp. 1-4) (IFAD, 2015, pp. 2, 7, 18-19, 20)

Figure 14 shows a basic structure of a fixed dome digestor. The digestor is built out of bricks and is located underground. The inlet, gas pipe and opening for overflow are on top of the ground level. As organic waste is fed inside the digestor, the level of the slurry increases. If the amount of gas is small, no overflow occurs. When the digestor is having more gas, the level in the outlet chamber increases and overflow occurs.

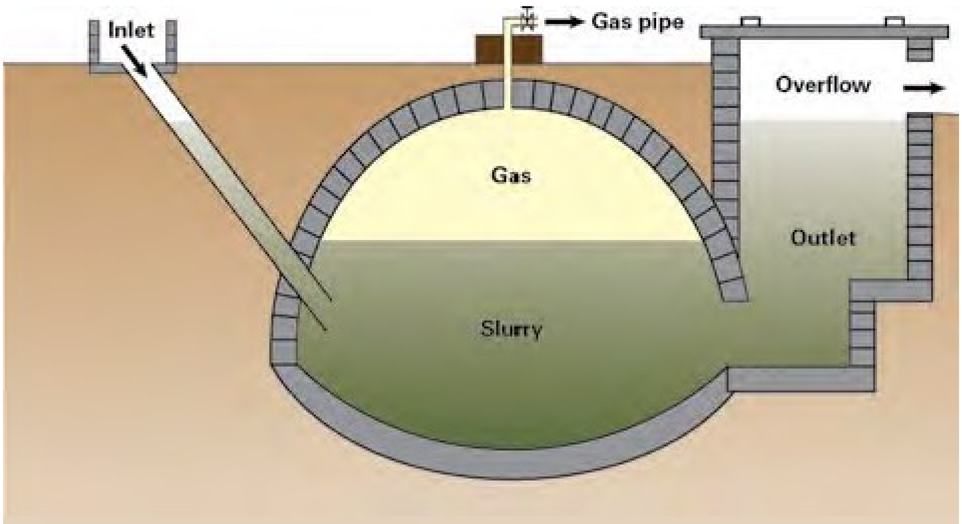

Figure 14. Fixed dome digestor. (Vögeli, Lohri, Gallardo, Diener, & Zurbrügg, 2014, p. 34)

4 BIOGAS RELATED CONDITIONS IN MARSABIT

The town of Marsabit is located in Marsabit county in northern Kenya (see Figure 15). It is 70 961 km^2, which makes it the largest county of Kenya. The town is set on an extinct volcano. While most of the Marsabit county is desert, the Town of Marsabit is surrounded by Marsabit National Park and Marsabit National Reserve having forest and crater lakes. (Kenya information guide, n.d.) (Wikipedia, n.d.)

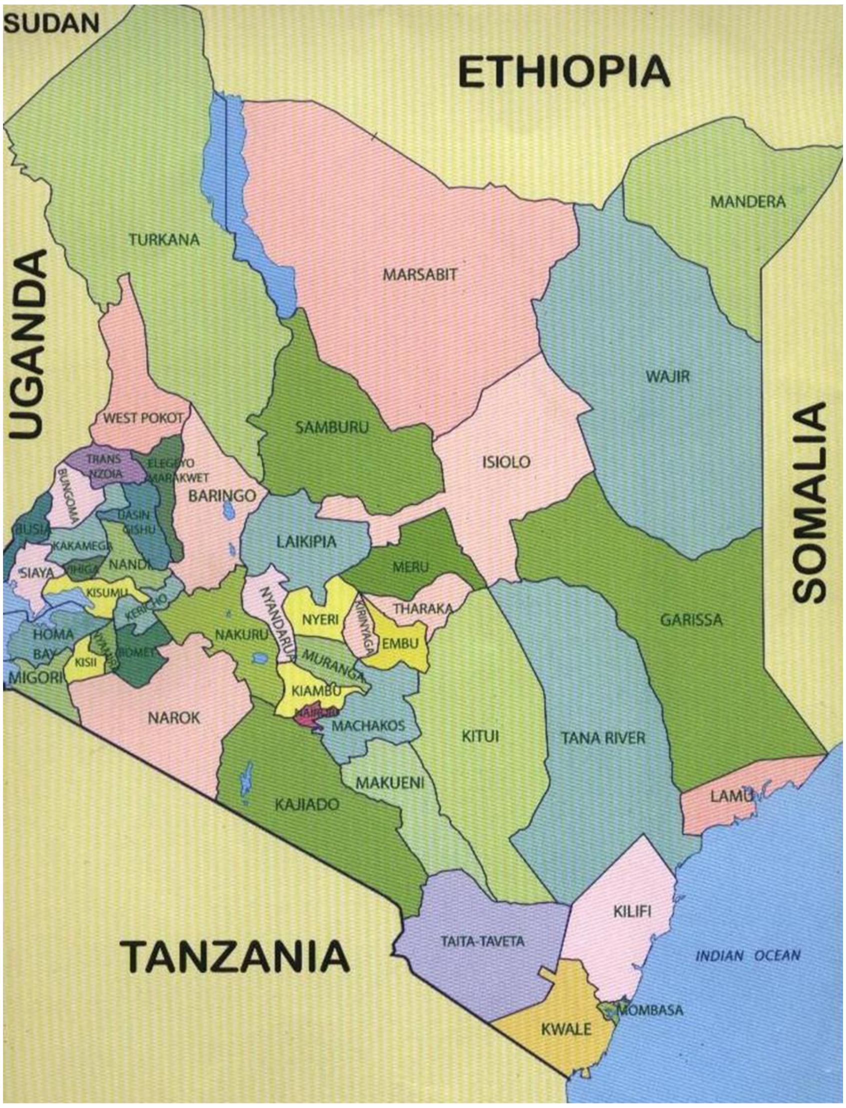

Figure 15. Map of Kenya. (IFAD, 2012, p. 46)

The temperature in Marsabit varies between 10,1-30,2°C. It is one of the driest counties of Kenya with the average precipitation of 254 mm (varying between 200-1000 mm/ year). The rainy seasons occur in April and November, during which most of the rainfall is received. Marsabit is considered an arid area. (Kenya information guide, n.d.)

Men and boys have traditionally been in charge of taking care of animals. Still majority of households are keeping livestock. Women and girls have been doing the daily chores, such as fetching water (average distance 4 km), firewood and cooking. (Kenya information guide, n.d.) (Barasa, 2016, p. 48)

According to the survey executed by HAMK students in Marsabit on 13.3.2017 the household size was varying between 1-17 people, average was 6,1 people. A total of 89 households were interviewed, and they were chosen to be the target group of the planned housing area.
The survey shows mainly small amounts of kitchen waste, 0,5-2 l/day, but there were cases of households reporting up to 10 l/ day of kitchen waste. Some reported to have no kitchen waste. Some households reported no kitchen waste at all. In the survey, only few families were having farm animals. Some families were having kitchen gardens and/ or fruit trees.

The average household size varies greatly in different social classes. Where as in lower class households the average size is 7,4 people, in households having higher education and better jobs the average is only 2,8. (Barasa, 2016, p. 42) The amount of faeces (wet mass) in Kenya per person in one year is 190 kg (Jönsson, Stinzing, Vinnerås, & Salomon, 2004, p. 7). This would mean 520-8840 g of human waste per day and in an average size of household 3852 g. The amount of faeces is significantly affected by the nutrition of the person and therefore the amount should be evaluated with in each household, if the manure is used and counted as a part of organic waste fed into the biodigester.

5 ADVANTAGES AND CHALLENGES USING BIOGAS

Kenyan government recognises the issues of climate change, deforestation, desertification, problems with water reservoir, land productivity, soil erosion etc. Lack of water and nutritious food are big issues. The issues are seen to get bigger due to the climate change, which is predicted to cause more extreme weather conditions. The government wants to promote renewable energy sources, such as biogas and for example increase the land coverage of forests. An increase of vegetation surface area will help for example for soil erosion and water issues. These same issues apply for Marsabit. (IFAD, 2019, pp. 13, 22, 25)

Marsabit has few forests and at the moment they are being cut down to provide fuel for cooking. Often, the forests are located a bit further away from the town, so women and children (mainly girls) have to spend hours to collect firewood and carry it home. This results in lack of time to attend education for girls. Some families also must buy the wood, coal or gas and a big portion of their income can go to this.

Cooking with wood (see Figure 16) or coal causes air pollution and respiratory diseases, eye infection and many deaths each year in developing countries. Especially women and children are affected by the smoke, since they spend time indoors while cooking. Use of biogas would eliminate smoke and problems that smoke causes, since it does not cause smoke while burning. Biogas burns with pure blue flame.

Figure 16. Smoke in the house. (HAMK, 2020)

Lack of water is a problem in Marsabit and the biogas digester does require water. Greywaters could be used as substitute to water if they do not have chemicals in them. Also, the effluent can be re-used in the biodigester. Since most of the water is required during the start-up for the biogas digester, it may be recommendable to start during the rainy season. The temperatures however may be lower then and this might cause a delay in the start-up process. The colder weather also affects the process, so seasonal fluctuation can be detected in the biogas formation.

When the forests are cut down in excessive amounts, it causes many problems for the local environment. It results in soil erosion and thus desertification. This also affects to the water reservoirs and therefore increase the problems with lack of water. By replacing at least some needed energy with biogas, the need for cutting wood could be decreased. However, for small households generating very less biowaste, biogas production might not be a suitable option. For bigger households with kitchen gardens and/ or fruit trees or other plants and some animals, biogas could be a very suitable alternative for cooking.

Surveys have shown that the usage of faeces (human and/or animal) for cooking and possibly as fertilizer for food, may be an issue (Vögeli, Lohri, Gallardo, Diener, & Zurbrügg, 2014, p. 15). If the household generates enough biowaste from other sources, such issues would not be a concern. There have been programs in Kenya where biogas operating on animal or human waste has been introduced and the general acceptance was satisfactory. With further education programs, a higher level of acceptance may be achieved. If growing food for humans with the effluent from the bio digestor based on human or animal waste is not accepted, the effluent could also be used for growing other trees and plants. Using effluent for the fruit trees, might also be accepted easier, since it is not directly touching the part meant for eating. This also removes the possible health hazard, although in many places the effluent has been utilized without aftertreatment with no issues. Also, when used within the same household where the waste has been generated, the hazards were not considered as risky as compared to effluent e.g. from municipal treatment plant. It must be kept in mind that the amount of pathogens is significantly reduced during the biogas production process. It is not, however, recommended to apply the effluent on the plants just before harvest, but preferably a bit earlier on the season. Also washing the vegetables well and preferably cooking them before eating is advisable. In low-income households, managing to grow themselves nutritious food in their own garden, may also affect positively to the health of family members.

By using human waste in the biogas digester, nutrients are cycled back to the food production. This is presented in Figure 17. The food crop is harvested from the kitchen garden and cooked by using biogas. After being digested by the human, it goes to the biogas digester, where it is converted into biogas and effluent. Biogas goes to the kitchen to be used in cooking and the effluent is put to the kitchen garden or other plants, which can be fed for animals. Animals produce manure, which can be put to the digestor to produce biogas and effluent. Garden waste can also be used straight in the digestor, without feeding it to people or livestock.

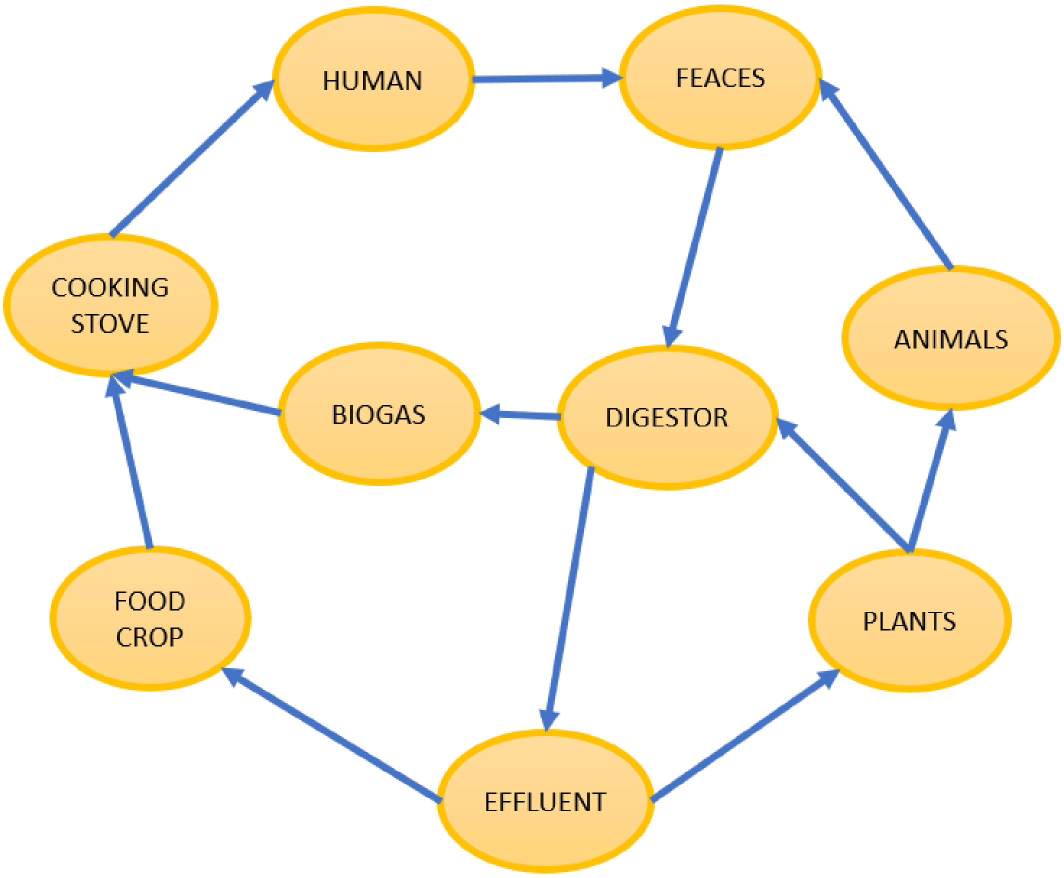

Figure 17. Nutrient cycle

Another common issue with biogas is that it may sound complicated and therefore people are not willing to try it. By finding few pioneers from the community, who could show how easy it is to make it work and what benefits it could bring for the household, the community would get more familiar with the idea. Programs which could help the locals with technical support at the beginning would furthermore encourage the use of biogas digesters. In case of lack of knowledge, the ready-made biogas digesters (e.g. Flexi Biogas) are a good option. These come with ready parts and instructions for building it up. Self-made plants provide cheaper options in case of existing knowledge and available materials for building them.

A good way of promoting biogas in the community could also be building a biogas digestor at the local school and involve children with it. This increases the odds that later on the children might accept the biogas easier.

6 CONLUSION

Marsabit has a dry and arid climate and it is one of the most underdeveloped counties in Kenya. It has been affected badly by climate change, furthermore, increasing the challenges of human life. The on-going project aims to build a climate smart and affordable housing area, as a pilot project which could lead to a wider-scale building of new housing areas, using same principles. In this new housing area, renewable energy technologies will be implemented. This thesis focused on producing biogas as means to generate a sustainable cooking method with minimum impacts on the environment.

At the moment in Marsabit, firewood is the most common source for cooking. Marsabit does not have forests to be cut for this purpose and the forests remaining there are protected. Cooking with firewood has led to deforestation, amongst other issues such as requiring strenuous work from women and young girls to fetch the wood from distant locations and minimizing their chances to attend education. Producing biogas successfully would tackle many of these issues at once.

Three typical biogas digesters are considered and found to be adequate for use in Marsabit. The IBC biodigester is the cheapest to build and the container itself may be found at a very low cost, considering that it is a problem waste. It requires the technical knowledge on how to build it but minimum expertise. It also operates with low feeding volumes, which makes it suitable for Marsabit use, considering the kitchen waste and garden waste may be low. Suggestions are given to use animal manure or human waste, as these may be available more easily. The Flexi Biogas can be purchased as a ready-to-use biogas digester. This is produced by a Kenyan company and although investment costs are higher than for the IBC biodigester, it offers a quick solution which requires no previous technical knowledge. Basic information on how to operate this digester and other technical support is given by the Flexi Biogas producer. Another possible biodigester which is suitable for use in Marsabit is the fixed dome. Bricks can be produced locally in Marsabit since raw material is available. The fixed dome biodigester is significantly more expensive than the two other options presented and requires technical expertise which may not be found locally. However, this also offers business opportunities with beneficial possibilities for the local economy. More waste is required to be fed in the fixed dome biodigester and this may be a better option for households with farm animals such as goats or cows.

The by-product of the biogas production is the effluent, which is very beneficial if applied as a fertilizer, considering the soil in Marsabit has very low fertility. This natural fertilizer can significantly boost the growth of plants and trees, counter the effect of the deforestation, erosion and help with issues such as lack of food. If animal or human waste is used, the biodigester effectively kills some of the pathogens, making the fertilizer safer to use. Additional treatment may not be required, however hygienic precautions should be taken and safe farming techniques applied (e.g. when to apply the fertilizer). The biogas on the other hand, besides used for cooking, can also be used for boiling drinking water as a primary treatment for it. Drinking untreated water is a common issue in Marsabit and biogas presents some solutions for this. Further treatment of water may be required however, and this was not investigated in this work.

Challenges of using biogas in Marsabit includes the low level of education which contributes to the reluctance of cooking with gas produced from e.g. human or animal waste. Other challenges remain the initial investment costs which may be high considering there are many households in Marsabit with no regular income. Biowaste such as kitchen waste and garden waste may not be very large in volume, and this may push for use of animal and human waste as a primary feed for the biodigester. With integrating biogas production in the teaching curriculums, organizing training with the local population and showcasing successful production of the biogas and its benefits, the general opinion if biogas production may shift to a more positive one and biogas production would be encouraged.

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